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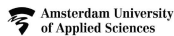
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When two become one: interpersonal pattern formation in side-by-side and hand-in-hand walking



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Introduction

When two persons are walking together, their footsteps sometimes spontaneously adjust to one another¹. Such episodes of entrainment likely enhance when holding hands²; the mechanical link affects arm-leg coordination of each walker and hence is expected to constrain between-walker stepping. We examined the effects of coupling strength (hand-in-hand vs. side-by-side) as well as detuning (pairs with either similar or different uncoupled cadences) on spontaneous pattern formation. Based on coupled oscillator dynamics we expected 1) higher occurrence of step synchronization in hand-in-hand than in side-by-side, and that 2) cadence-matched pairs synchronize steps more often than detuned pairs.

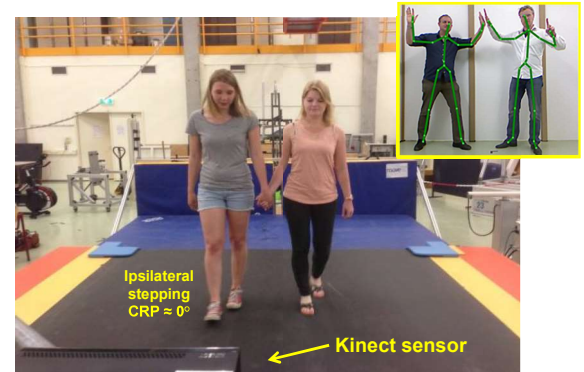


Figure 1. Picture of the experimental setup. In this example, the pair is low-detuned and walks in ipsilateral phase-locking mode ($CRP \approx 0^\circ$). The yellow inlay (top right) illustrates the Kinect v2 skeletal model.

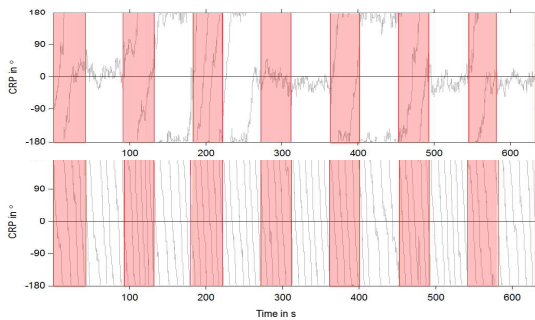


Figure 2. Typical examples of CRP time series in a low-detuning pair (upper panel) and high-detuning pair (lower panel). Episodes indicated with pink color depict the side-by-side stages.

Methods

Based on the step frequency observed a priori in solo walking, we formed 8 low-detuning pairs (mean absolute difference of 0.37 steps/min) and 8 high-detuning pairs (mean absolute difference of 4.48 steps/min). Pairs walked ± 11 minutes on a huge treadmill (Figure 1)¹ at a strolling tempo of 1.3km/h, alternating between episodes of 45 s. hand-in-hand (7 episodes) and side-by-side (7 episodes). Full-body 3D kinematics were captured at 30 Hz with Kinect v2 (see yellow inlay in Figure 1)³. From this data the continuous relative phase (CRP) between the displacements of a pair's ipsilateral legs (i.e., left leg of one and left leg of other) was determined.

Results and Discussion

As expected, there was greater occurrence of phase-locking for hand-in-hand than for side-by-side walking, especially for the low-detuning pairs (see Figures 2 and 3). Notably, for hand-in-hand synchronization of left and right legs (ipsilateral phase-locking: $CRP \approx 0^\circ$) occurred more often than synchronization of inner and outer legs (contralateral phase-locking: $CRP \approx 180^\circ$). This could be explained by the lateral sway that humans show at low walking tempos, much like waddling penguins (Figure 4). Due to such waddling, contralateral stepping involves strong reduction of interpersonal distance at instances of inner leg stance (Figure 4, left panel), with possible collision of the bodies and hence perturbation of the between-person pattern.

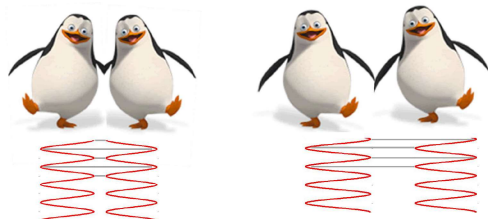


Figure 4. Schematic illustration of the effect of waddling on the between-person distance for contralateral stepping (left panel) and ipsilateral stepping (right panel)

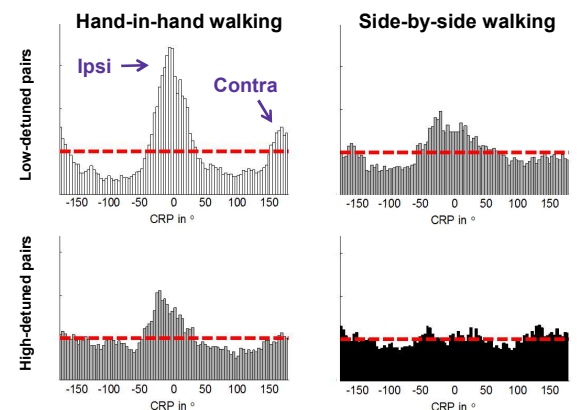


Figure 3. Histograms of occurrences of CRP values in each condition, collapsed over all designated pairs. The red dotted line indicates equal distribution.

Conclusions

- Due to the stronger (mechanical) coupling, hand-in-hand walking gives rise to enhanced between-person synchronization.
- Sync-effects are much weaker in pairs with highly detuned individual cadences.
- Preference for ipsilateral stepping mediated through lateral sway

Literature

- [1] van Ulzen, N. R., et al. (2008). Characteristics of instructed and uninstructed interpersonal coordination while walking side-by-side. *Neuroscience letters*, 432(2), 88-93.
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